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Additive manufacturing of mirror components for space

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European synchrotron radiation facility: **Christian Morawe, F. Perrin**

Laboratoire d’astrophysique de Marseille: **Melanie Roulet**

National Physical Laboratory: **Wenjuan Sun, Peter Cooper**

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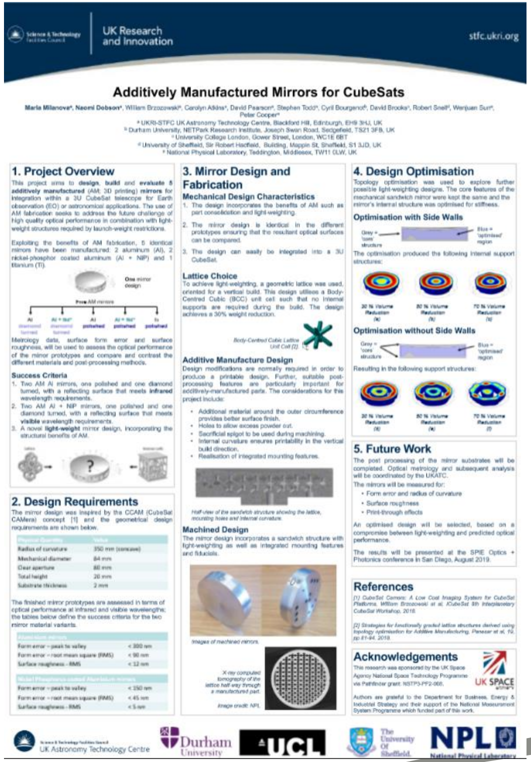
Context



This presentation is linked to the poster presented yesterday:
Additively manufactured mirrors for CubeSats

The results described in this presentation highlight the optical performance expectation for the CubeSat substrates.

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Outline

1. Motivation and approach
2. AM mirror example #1 – good surface roughness can be achieved
3. AM mirror example #2 – lightweighting comparison
4. Conclusion

Motivation: why additive manufacturing?

To utilise the design freedom of AM to create bespoke hardware that is more tailored to function than tailored to manufacturability.

Question: Why create mirrors via AM?

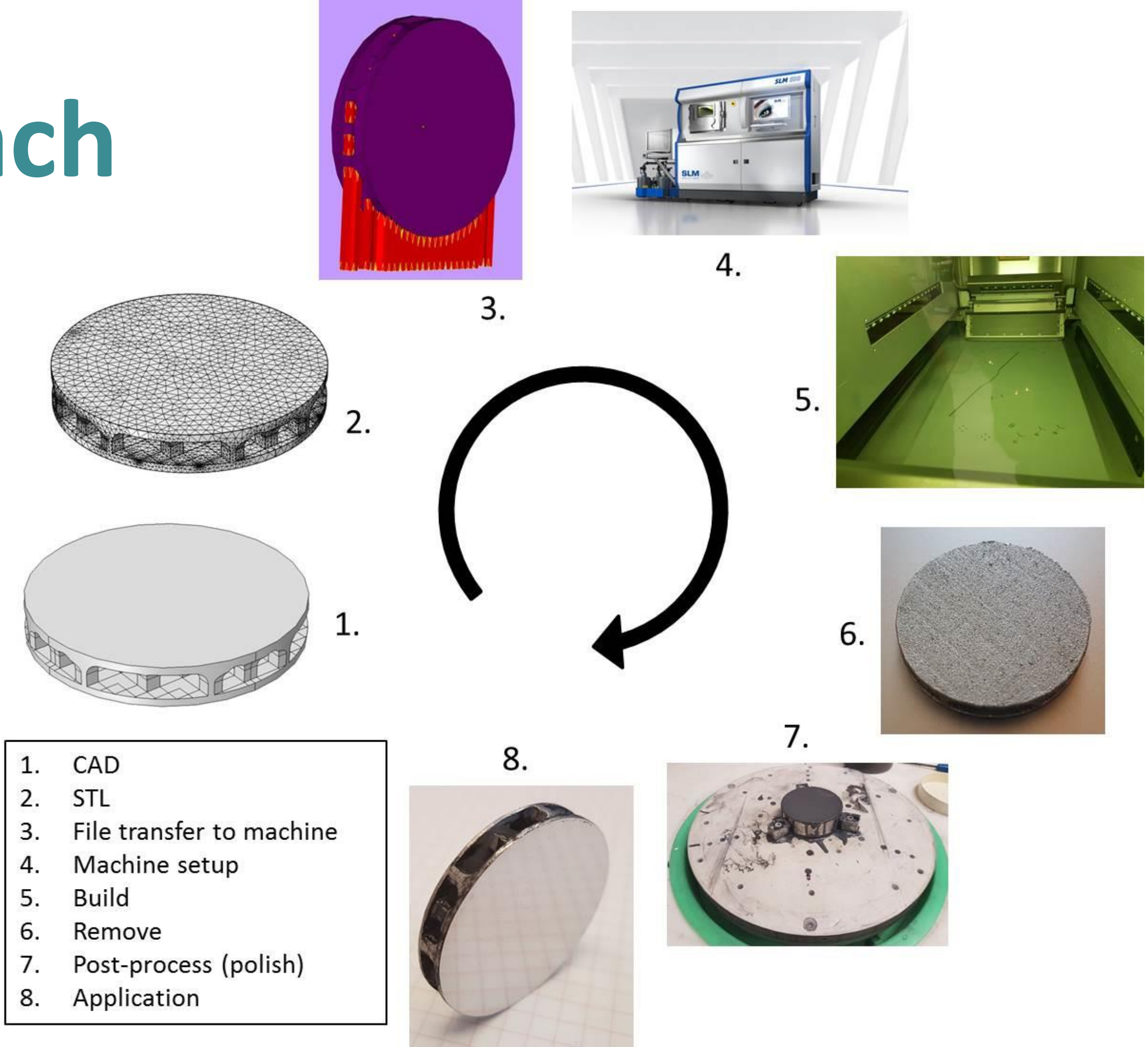
To develop mirrors more suited to their environmental constraints:

- Optimised light-weighting
- Integrated mounting or functionality.

Question: *Why create AM mirrors for space?*

- Reduce weight
- Optimise volume use
- Demise-ability

Approach



1. CAD
2. STL
3. File transfer to machine
4. Machine setup
5. Build
6. Remove
7. Post-process (polish)
8. Application

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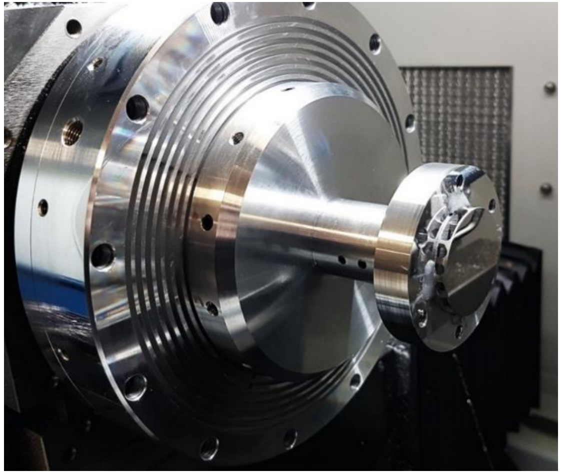
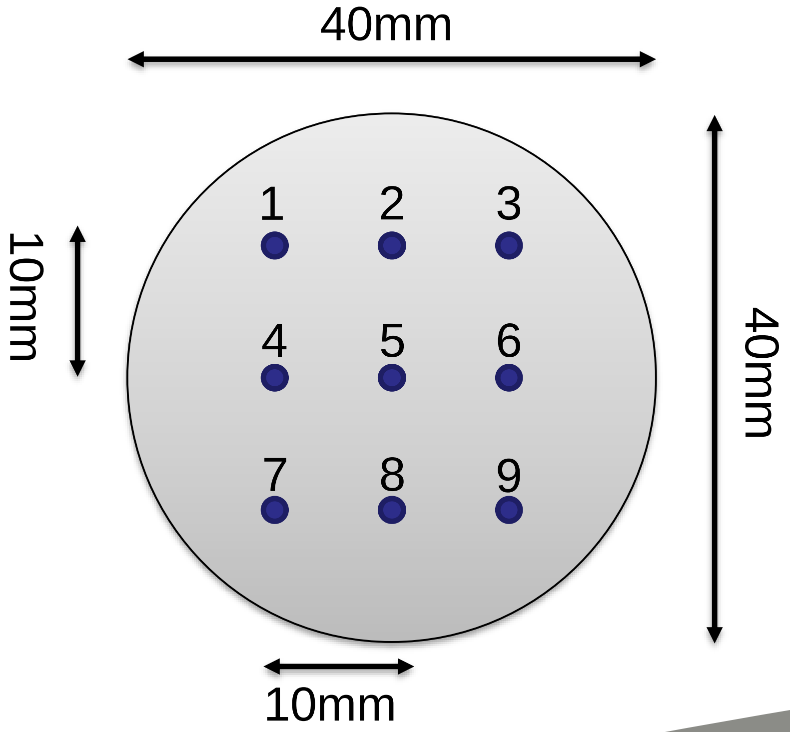
AM Example #1: the aluminium mirror



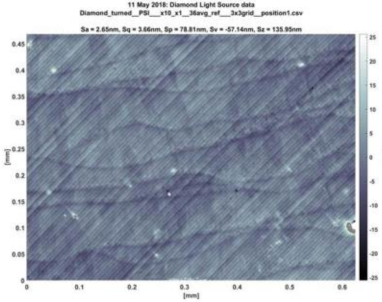
Dimensions: 40mm in diameter, 6mm in height, **optically flat**
Material: aluminium ($AlSi_{10}Mg$)
Lightweight percentage: ~44% mass remaining (ratio = 9g/20.36g)
Single Point Diamond Turning: RAL Space PDF

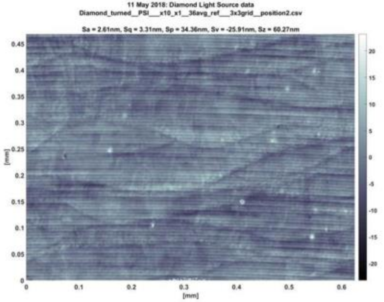
Diamond-turned AM mirror

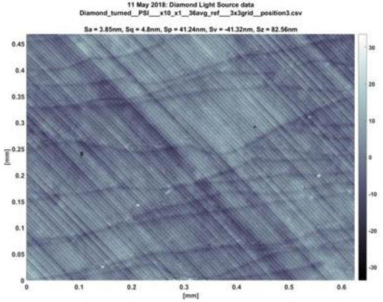


Surface roughness:

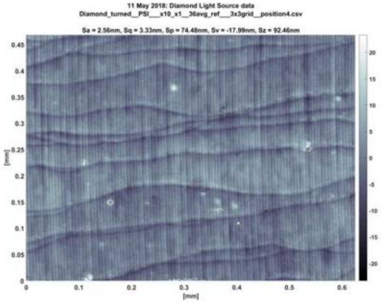
- Facility: Diamond Light Source
- Instrument: Bruker Contour GT-X stitching microinterferometer
- 3 magnifications evaluated: 5x, 10x and 50x

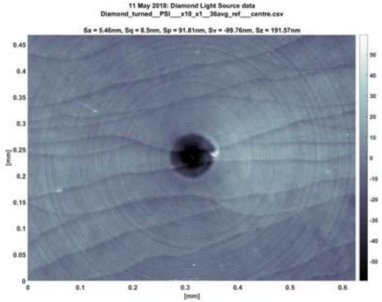


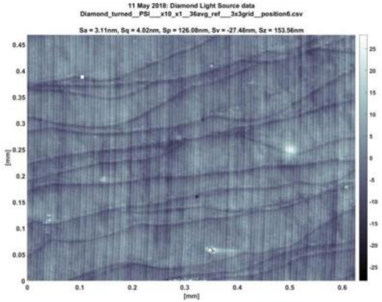


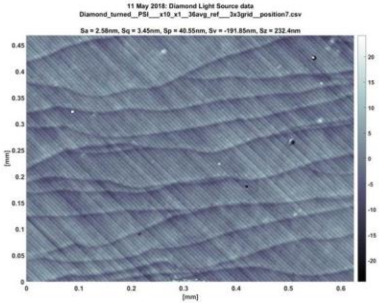


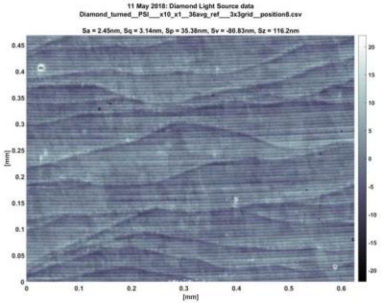
10x magnification



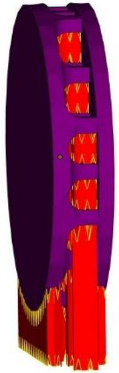








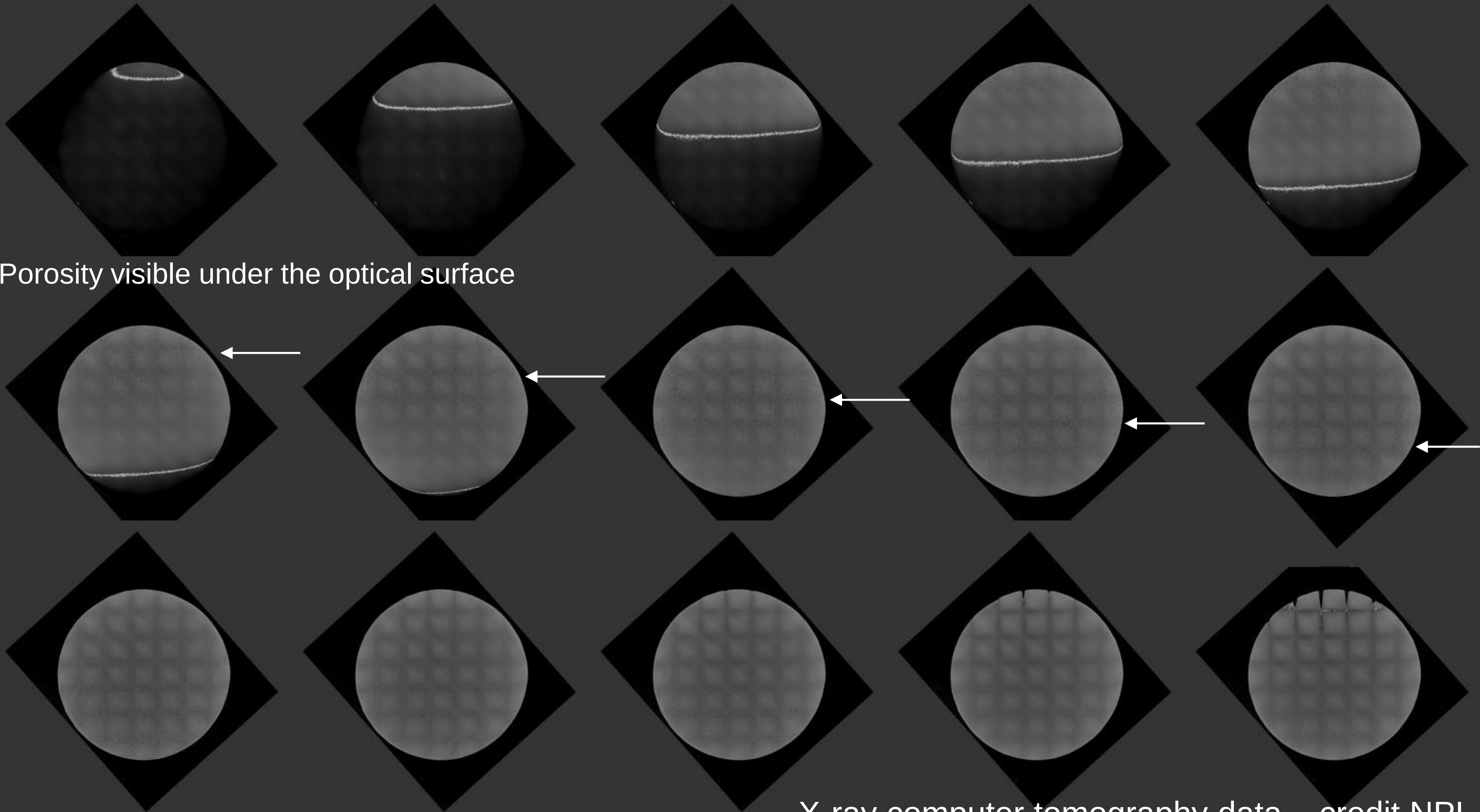
Build direction



Surface roughness data

Surface roughness measurements						
3x3 Grid	5x magnification		10x magnification		50x magnification	
	RMS[nm]	PV[nm]	RMS[nm]	PV[nm]	RMS[nm]	PV[nm]
Ave.	**3.28**	**91.41**	**3.66**	**117.95**	**3.84**	**40.56**
Max.	5.00	105.82	4.80	232.40	4.92	66.25
Min.	2.55	67.04	3.14	60.27	3.10	24.08

… these are good values for aluminium, where's the porosity?



X-ray computer tomography data – credit NPL

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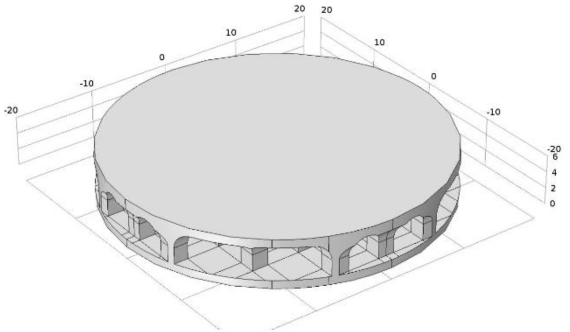
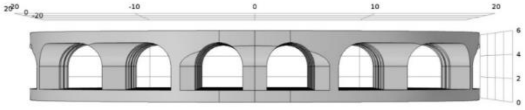
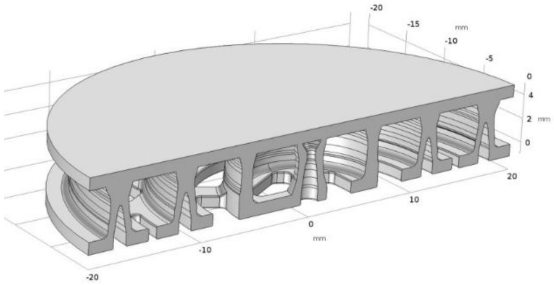
Design optimisation

40mm diameter, 6mm in height, top and bottom substrate thickness 1mm.





40mm diameter, 5mm in height, top and bottom substrate thickness 0.5mm.



Design output from topology optimisation – light-weighting designed to compensate for polishing pressure

Core research discussed in: *Atkins, C. et al., "Additive manufactured x-ray optics for astronomy", Proc. SPIE 10399, 103991G, 2017.*

Design comparison

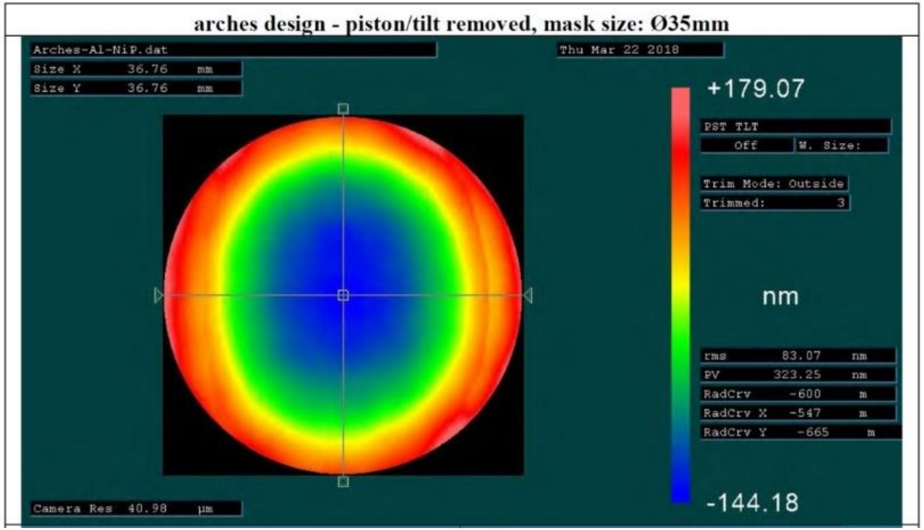
Material: AM aluminium ($AlSi_{10}Mg$)
Coating: nickel phosphorous (NiP)
Diameter: 40mm

Ensures a pore free surface to polish

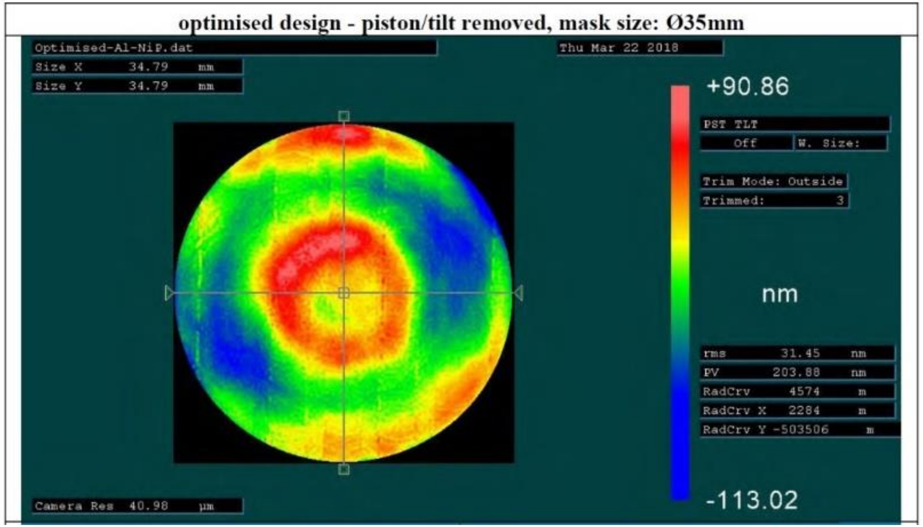
Substrate thickness: 1mm
Weight: 14.3g

Substrate thickness: 0.5mm
Weight: 11.7g

Form error after polishing



arches design - piston/tilt removed, mask size: Ø35mm



optimised design - piston/tilt removed, mask size: Ø35mm

Surface form error:

- Facility: European Synchrotron Radiation Facility
- Instrument: ZYGO GPI – XPZ, λ = 632.8nm

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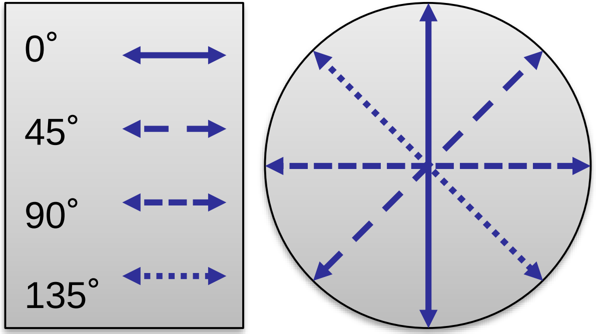
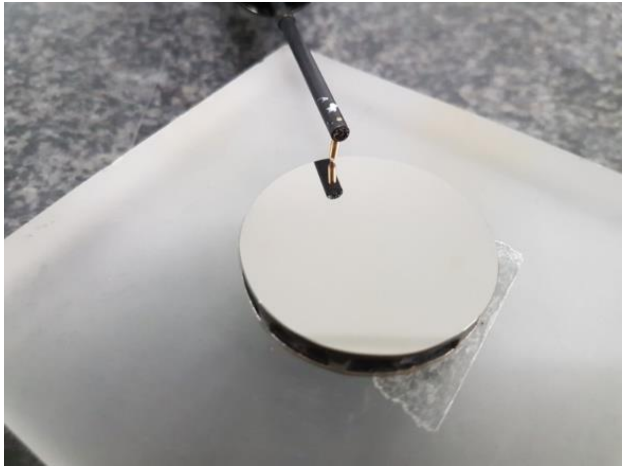
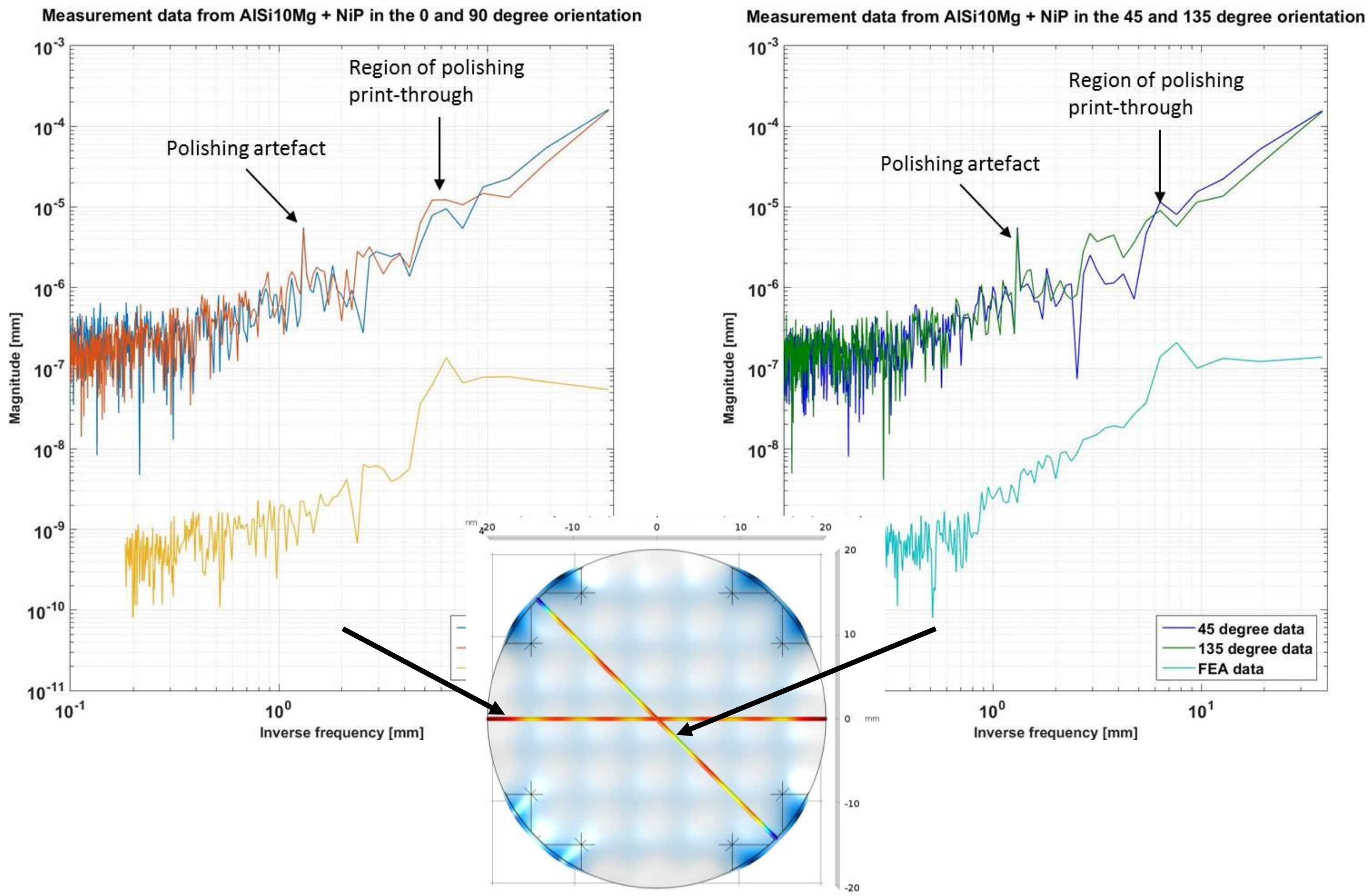
Does the light-weighting print-through?

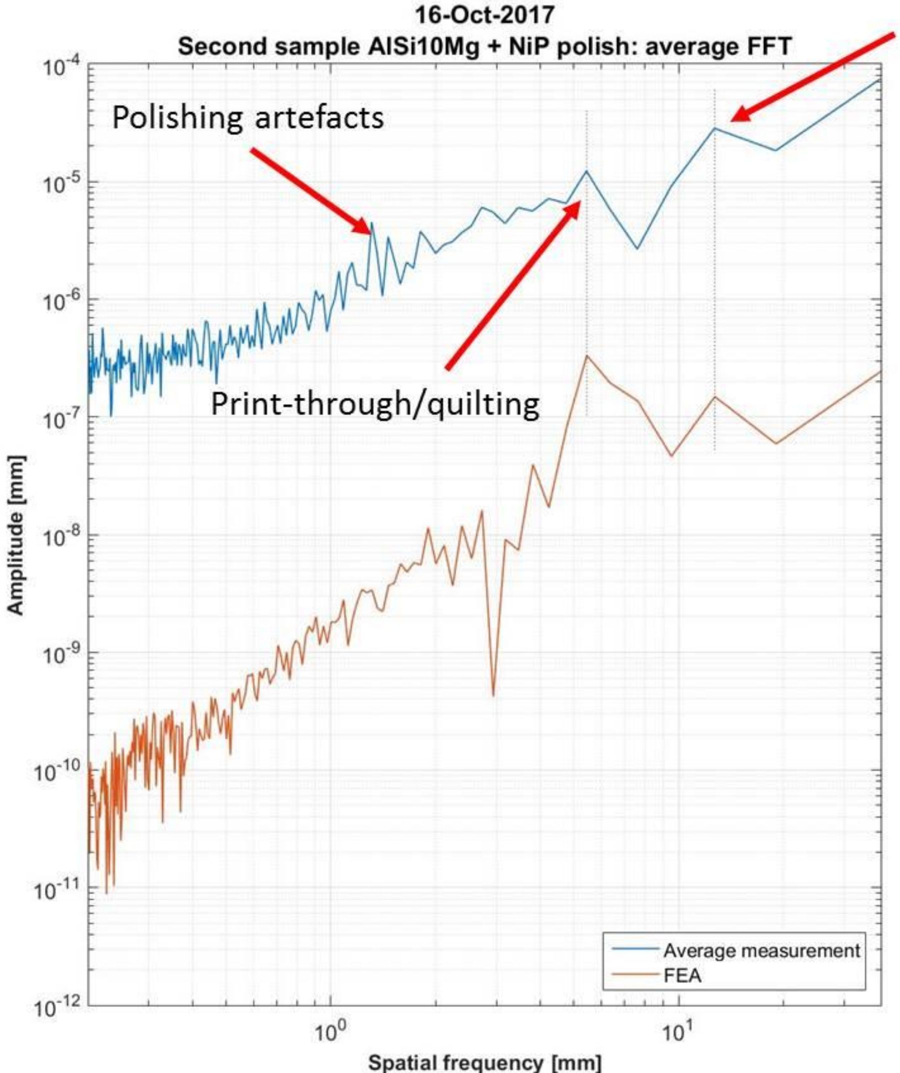




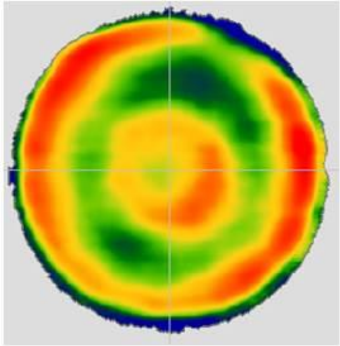
Profilometry data:

- Facility: Glyndwr Innovations
- Instrument: Taylor Hobson Form Talysurf Intra.

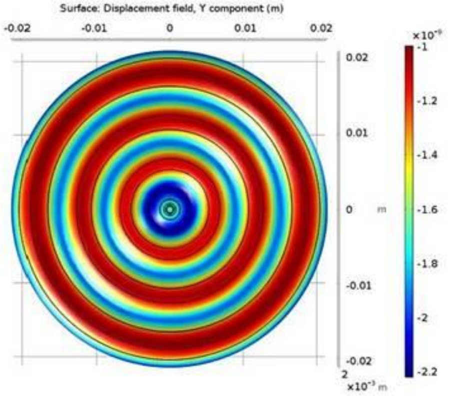

Measurement data from AlSi10Mg + NiP in the 0 and 90 degree orientation
Measurement data from AlSi10Mg + NiP in the 45 and 135 degree orientation
Region of polishing print-through
Polishing artefact
Region of polishing print-through
Polishing artefact
Magnitude [mm]
Inverse frequency [mm]
Magnitude [mm]
Inverse frequency [mm]
45 degree data
135 degree data
FEA data



Form seen in interferometer



FEA print-through map



Optical form

Form error	Non-optimised	Optimised
PV [nm]	323.25	203.88
RMS [nm]	83.07	31.45
Weight [g]	14.3	11.7
Roughness [x5 magnification]		
RMS [nm]	3.37	6.04
Print-through of light-weighting [FFT]		
Amplitude [nm]	<10nm	~10nm

Take away

1. Reasonable form error can be achieved using AM substrates.
2. Computer optimisation is worth the time investment.

These results demonstrate a first effort in this research area

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Predicted impact

- Access to missions:
  - Use of AM mirrors could be applied where ever optical elements are required within a system.
- Mission enablement:
  - Allows more innovative, weight saving designs.
  - Cost – AM mirrors are no more expensive than traditional lightweight mirrors, perhaps less so.
  - Less weight per aperture area.
- Science enablement:
  - Larger collection area for a given mass restriction.
- Commercial:
  - Many of the big companies already have the required AM capability to build these parts.

Acknowledgements

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